ELECTROMAGNETIC INTERFERENCE AND ITS EFFECTS ON ULTRA-WIDEBAND TECHNOLOGY IN THE OPERATING ROOM

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Abstract-**Use of ultra-wideband (UWB) technology in the operating room (OR) has not been widely researched. UWB systems have inherent advantages in indoor environments due to suppression of multipath effects, which makes them strongly suited for use in typical hospital environments. The application of UWB systems for indoor localization will be discussed, including how electromagnetic interference (EMI) affects the standard UWB frequency range of 3.1 - 10.6 GHz. EMI was measured intraoperatively from 200 MHz – 26 GHz during four orthopedic surgeries. A summary of these results are presented including their implications on the performance of radio frequency identification (RFID) and UWB localization systems in the OR.**
Keywords - **UWB, operating room, indoor localization**

I. INTRODUCTION

The interest in ultra-wideband (UWB) technology for communication systems has increased greatly over the last few years following the Federal Communications Committee's decision to open up the band from 3.1 - 10.6 GHz for UWB use in 2002 [1]. Much of this research has been devoted to the use of UWB for digital communication. Hentila et al. did an extensive analysis of UWB channels in different hospital environments including the operating room (OR), X-ray examination room, and intensive care unit [2]. Although extensive research exists on performance of UWB channels for digital communication in indoor environments (including hospitals), much less has been done on performance of UWB local positioning systems in hospital environments. Clarke et al. tested commercially available radio frequency identification (RFID) systems in a standard OR, including an UWB system [3]. System accuracy was measured by percentage of failed cases in identifying RFID tags at various locations around the OR. The UWB system had the best performance when compared to other precise localization systems including Wi-Fi and an RF-based tracker.

UWB localization systems have inherent advantages in dense multipath environments such as the OR. This includes a wide bandwidth which makes them resistant to severe multipath and excellent time domain resolution which can be utilized in tracking applications [4]. The purpose of this research was to measure electromagnetic interference (EMI) in the OR across a wide frequency range in the context of comparing the useable frequency bands for an UWB localization system with frequency bands currently being used by other RFID systems. The paper is organized as follows: Section II presents the setup used to obtain measurements including discussion of the OR indoor environment, Section III presents the results, Section IV discusses their relevance for UWB localization systems, and finally Section V concludes.

II. METHODOLOGY

A. OR Indoor Environment

EMI was measured over a large frequency band (200 MHz – 26 GHz) in the OR during four separate orthopedic surgeries. Fig. 1 shows a layout of the dual OR. Two ORs allow a faster turn-around time in completing the four surgeries. Fig. 2 shows the experimental setup in the OR. Besides the operating table, numerous other pieces of medical equipment were present during the surgery including an anesthesia machine, ventilator, surgical lamps, various monitoring equipment, visualization screens, carts containing necessary orthopedic surgical tools, drills, etc. Also, numerous people were present including the surgical team, orthopedic company representatives, and spectators observing the surgery. The combination of people and medical equipment closely packed into the OR creates a dense multipath indoor environment that can greatly disrupt standard RFID tracking systems. UWB localization systems have inherent advantages that make them a strong candidate for use in dense multipath environments such as the OR.

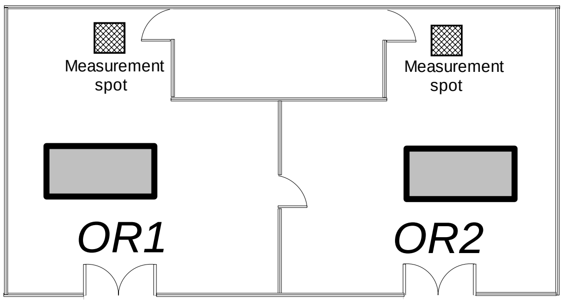

Fig. 1. Layout of dual operating room including operating tables and measurement locations.

Fig. 2. Experimental setup in the OR.

B. Measurement Setup

Various hardware was needed to get accurate measurements across the wide band of 200 MHz – 26 GHz. Table I summarizes all of the equipment needed in running this experiment. It should be noted that all reported gain and noise figure values are averages across the frequency range of operation. Fig. 3 shows the four antennas used to cover the entire frequency range. The standard setup for each of the frequency bands measured included an antenna, two stages of amplification, and a spectrum analyzer for visualization. Commercial off-the-shelf components were used whenever possible.

Using the hardware summarized in Table I, four setups were needed to cover the entire frequency range. From 200 MHz – 800 MHz, the biconical antenna (Fig. 3a) and two Hittite HMC465 LNAs were used. From 800 MHz – 3 GHz, both disc and horn antennas (Figs. 3b and 3c), a Mini-circuits ZX60-3011 LNA, and a Hittite HMC465 LNA were used. From 3 GHz – 18 GHz, the broadband horn (Fig. 3c) and two Hittite HMC465 LNAs were used. Finally, from 18 GHz – 26 GHz, the Vivaldi 4-element array (Fig. 3d) and two HMC517 LNAs were used.

Before conducting the experiment, it was assumed that most of the EMI detected would be in the range of 200 MHz – 3 GHz. This conclusion was made because WLAN and Bluetooth transceivers (operating at 2.4 – 2.48 GHz) were already present in the OR. Also, this frequency range covers GPS (1.575 GHz), US cellular phone frequencies, and a number of medical bands. Table II lists the major medical, scientific, and UWB frequency bands in the US and Europe [1,5,6]. A majority of the scientific and medical bands in both Europe and the US fall between the frequencies of 200 MHz – 3 GHz. Also, most RFID systems operate in the MHz range up to 3 GHz. Even though RFID systems can operate at 5.8 GHz or 24.125 GHz, limitations still exist on how well a system with small bandwidth can handle the dense multipath environment of the OR at these high frequencies. When looking at different wireless bands currently in use, whether WLAN, cellular phones, GPS, or medical, the advantages of operating in the higher frequency bands of 3.1 – 10.6 GHz and 22 – 29 GHz useable for UWB become clear.

TABLE I
HARDWARE USED IN BROADBAND OR MEASUREMENTS

Device	Model # / Type	Frequency	Gain (dB)	Noise Fig. / Pattern
LNA	Mini-circuits ZX60-3011	400 MHz – 3 GHz	10	1.6 dB
LNA	Hittite HMC465	DC - 20 GHz	15	3.5 dB
LNA	Hittite HMC517	17 – 26 GHz	19	2.7 dB
Antenna - A	TDK MBA-2501 Biconical	250 MHz – 1 GHz	23	Omni-directional
Antenna - B	Kathrein Scala 800-10249 Disc	824 – 960 MHz, 1.425 – 3.6 GHz, 5.15 – 6 GHz	2	Omni-directional
Antenna - C	Double ridged TEM horn	1 – 18 GHz	8	Directive
Antenna - D	Vivaldi array – 4 element	18 – 26 GHz	10	Directive
Spectrum Analyzer	Agilent E4407B ESA-E	9 kHz – 26.5 GHz	n/a	n/a

TABLE II
MEDICAL AND UWB FREQUENCY BANDS

Location	Frequency Band	Frequency (MHz)
US	Medical Implant Communications Service	402 - 405
US	Wireless Medical Telemetry Service	608 - 614 1395 - 1400 1427 - 1432
US	Instrumentation, Scientific, and Medical (ISM)	315 902 - 928 2400 – 2500 5150 - 5875
Europe	ISM	433.05 - 434.79 868 - 870 (short-range) 2400 - 2500
US	UWB	3.1 – 10.6 GHz 22 – 29 GHz, center freq > 24.075 GHz

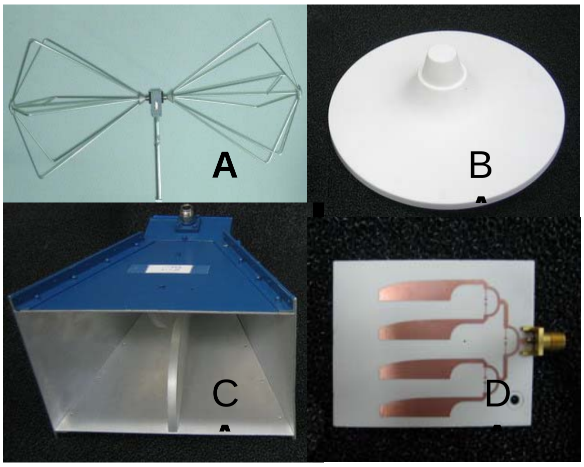

Fig. 3. Antennas used in OR measurements: a) biconical, b) multiband disc, c) broadband TEM horn, d) 4-element Vivaldi array.

III. RESULTS

Using the equipment setup described in Section II, EMI was measured over the frequency range of 200 MHz – 26 GHz. The results from these measurements can be seen in Figs. 4-6. A number of signals were detected in the lower frequency range of 400 MHz – 2.5 GHz. As shown in Fig. 4, no appreciable signals were picked up between 200–800 MHz. Although there is a small spike near 470 MHz, it is only 6 dB above the noise floor and is considered noise.

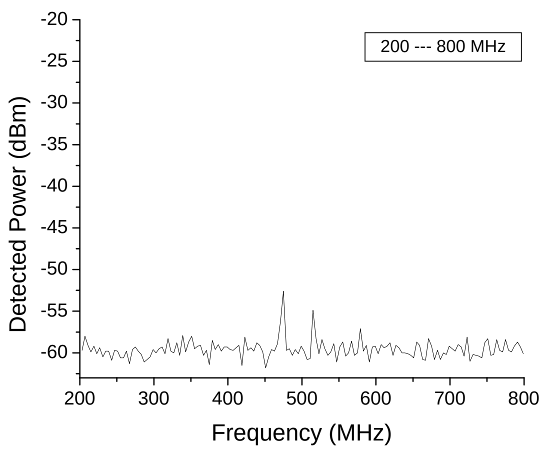

Fig. 4. Measured EMI over frequency range of 200 – 800 MHz.

Also, there are no licensed frequency bands in the US that could correspond to the 470 MHz peak.

Fig. 5 shows the frequency band from 800 MHz – 3 GHz. A number of different signals were found in this frequency range. The two strongest signals, which were found at 872 MHz and 928 MHz, correspond to CDMA2000 uplinks and downlinks (US cellular bands). The peak at 1.95 GHz also corresponds to a US cellular band. Finally, the peak at 2.4 GHz is caused by WLAN and Bluetooth components. Fig. 6 shows the frequency band from 3 – 26 GHz. No noticeable signals were picked up across this entire band. This is somewhat unexpected since there are ISM and WLAN bands between 5 – 6 GHz.

IV. DISCUSSION

The frequency bands containing noticeable EMI correspond to widespread technologies that will likely be seen in the average OR. One surprise was the almost complete absence of US scientific and medical bands. Many medical devices do conduct wireless operations at the frequency bands summarized in Table II, but besides the WLAN signal at 2.4 GHz seen in Fig. 5, no significant EMI corresponding to these frequency bands was detected in the OR.

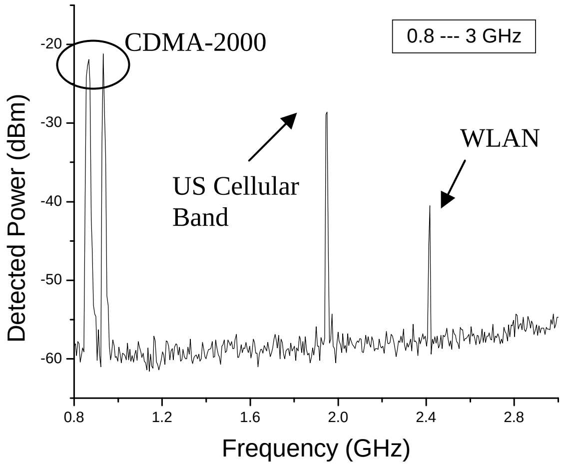

Fig. 5. Measured EMI over frequency range of 800 MHz – 3 GHz.

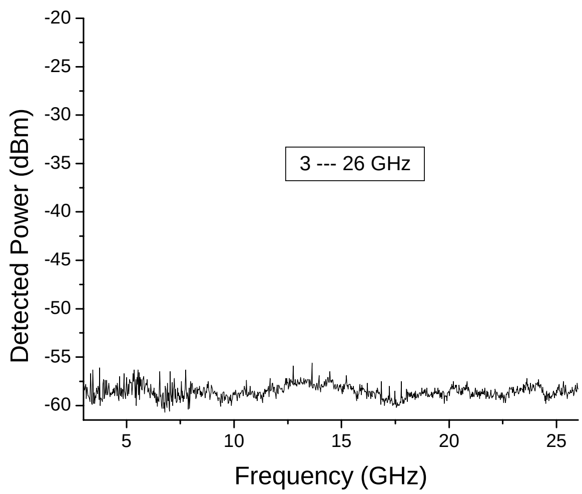

Fig. 6. Measured EMI over frequency range of 3 – 26 GHz.

Unfortunately there are some technologies that operate in frequency bands in the lower UWB spectrum (3.1 – 10.6 GHz), including ISM at 5.15 – 5.875 GHz, WiMAX at 3.3 – 3.8 GHz, 5.15 – 5.35 GHz, and 5.75 – 5.825 GHz, and WLAN at 5.47 – 5.825 GHz. These technologies will directly interfere with an RFID localization system operating at 5.8 GHz. Some fixes to block WLAN and WiMAX signals from UWB systems include integrating a notch filter into the UWB antenna design [7]. Although this could provide a viable solution, another notch filter would need to be used to block licensed frequencies in the 3 – 4 GHz range (e.g. WiMAX). The feasibility of using notch filters to block all possible frequency bands while still being able to correctly transmit an UWB pulse waveform is low. A more feasible solution for an UWB localization system is to operate in the higher part of the 3.1 – 10.6 GHz band. One feasible band currently being investigated stretches from 6 – 10 GHz with a carrier frequency of 8 GHz [8].

As outlined in Table II, there is another UWB frequency band from 22 – 29 GHz that can be used for localization systems. As seen from Fig. 6, there is no EMI in the band from 22 – 26 GHz. One reason for having no EMI is that very few licensed bands exist between 22 – 29 GHz that would affect an OR (most are used for astronomy). Also, signals in this frequency band tend to be attenuated more by the atmosphere and are typically used for short range applications. Using UWB for localization in the OR holds a distinct advantage over other technologies because of both the large bandwidth used as well as the higher frequencies available for operation.

V. CONCLUSION

An experiment has been conducted in the OR during four orthopedic surgeries to measure EMI across the large frequency band of 200 MHz – 26 GHz. A description of the OR was given, including the large amount of equipment and people which make it such a dense multipath environment. An overview of the hardware needed was also presented. Commercial components were used whenever possible to facilitate conducting the experiment. Four separate broadband and multiband antennas and many broadband LNAs were needed to cover the entire frequency range. Relevant medical, scientific, and wireless bands have been outlined in the context of which signals were present in the OR and how they may affect RFID and UWB frequency bands. The whole analysis has been undertaken with the intent of comparing use of UWB technology versus other technology such as RFID for localization systems operating inside the OR. UWB has a number of distinct advantages in the frequency ranges in which it is allowed to operate. This is due to both the higher frequency bands for which it is allocated as well as the wide bandwidth it is allowed to use.

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